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Parametric Optimization of Gravity Die Casting Process Using FEA-DOE Hybrid Modeling

KEYWORDS: GRAVITY DIE CASTING, DESIGN OF EXPERIMENT, PROCAST

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ABSTRACT *Porosity may be the most persistent and common complaint of casting users. The conventional trial and error based die design and process development is expensive and time consuming. This paper describe the FEM based simulation software systems to the designer to visualize the metal flow in the die cavity, the temperature variations, the solidification progress, and the evolution of defects such as shrinkage porosities, cold shuts, hot tears and so on. Computer simulation procedure based process development and die design can be used for rapid process development and die design in a shorter time. Such a computer simulation based procedure, often using state of the art FINITE ELEMENT ANALYSIS based software systems, and DESING OF EXPERIMENT method can improve the quality and enhance productivity. By applying DOE method we can reduce Numbers of trials, Optimal setting of the parameters can be found out and Experimental error can be estimated.*

1. INTRODUCTION

Gravity die casting used for non-ferrous casting applications is increasingly used in the foundries today as an economically viable casting process. The conventional trial and error based die design and process development is expensive and time consuming. Such a procedure also might lead to higher rejections and lower casting yield. Computer simulation procedure based process development and die design can be used for rapid process development and die design in a shorter time. Such a computer simulation based procedure, often

Using state of the art FINITE ELEMENT ANALYSIS based software systems, can improve the quality and enhance productivity of the enterprise by way of faster development of new product. FEM based simulation software systems help the designer to visualize the metal flow in the die cavity, the temperature variations, the solidification progress, and the evolution of defects such as shrinkage porosities, cold shuts, hot tears and so on. The common defected gravity die cast components are shown in figure 1.1 and figure 1.2.

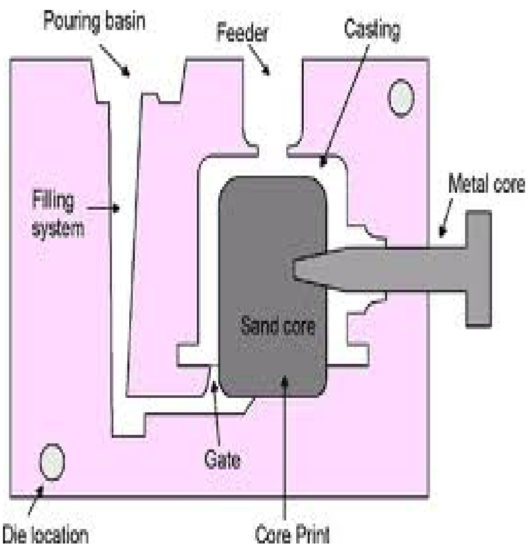

Figure1.1 Gravity die casting

Figure 1.2 Defected shell core drum

Casting process is also known as process of uncertainty. Even in a completely controlled process, defects in casting are found out which challenges explanation about the cause of casting defects. The complexity of the process is due to the involvement of the various disciplines of science and engineering with casting. The cause of defects is often a combination of several factors rather than a single one. When these various factors are combined, the root cause of a casting defect can actually become a mystery. It is important to correctly identify the defect symptoms prior to assigning the cause to the problem. False remedies not only fail to solve the problem, they can confuse the issues and make it more difficult to cure the defect. Unfortunately, this is not an easy task, since casting process involves complex interactions among various parameters and operations related to metal composition, methods design, molding, melting, pouring, shake-out, fettling and machining. The proper classification and identification of a particular defect is the basic need to correct and control the quality of casting. To enhance the quality of cast component the solid model is analyzed and experimental results are compared with the finite element

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analysis results to optimize the design specification and parameter. Therefore this paper concentrates on the comparison of actual modeled and analyzed die cast model.

2. REVIEW

Feng Liu et al [1] in this paper, with the aid of parametric modeling technology of runner and riser are modeled parametrically. By varying each parameter, it is easy to get different casting CAD models. These models output data populate the orthogonal matrix, which is used in the orthogonal array testing strategy to define the most suitable combinations of runners and risers parameters. After inputting the completed orthogonal matrix data and all CAD models into the simulation software the simulation result can be obtained. Marco Aloe et al [2] observed that Gating systems, overflows, venting channels can be optimized using numerical simulation. Solidification related defects can also be predicted taking into account cooling channels and die cycling so as to accurately reproduce production conditions. ProCAST readily addresses all these issues but also includes advanced features to better assess the casting quality. Mohammad Sadeghi et al [3] observed that ProCAST software used to simulate the fluid flow and solidification step of the part, and the results were verified by experimental measurements. By this Paper he concludes that 1) Comparison of the experimental and simulation results indicates that defects in the pieces are placed at the predicted places by simulation. 2) If the die temperature is reduced from the optimum temperature range, probability of cold flow defects and air porosities increase. 3) Determination of optimized places of overflows by simulation led to decrease of some casting defects such as cold shots and air porosities. Dr. S. Shamasundar et al [4] observed that in gravity die casting of Aluminium parts, computer simulation can be a useful tool for rapid process development. Limitation of the conventional die design and gating design has been elaborated. Advantages of computer simulation based design enumerated. The procedures thus described have been demonstrated with two case studies of application of ProCAST simulation at Ennore Foundries. It is demonstrated that the foundries can derive mileage by resorting to FEM simulations of the casting process for process development and optimization as shown in figure 2.1.

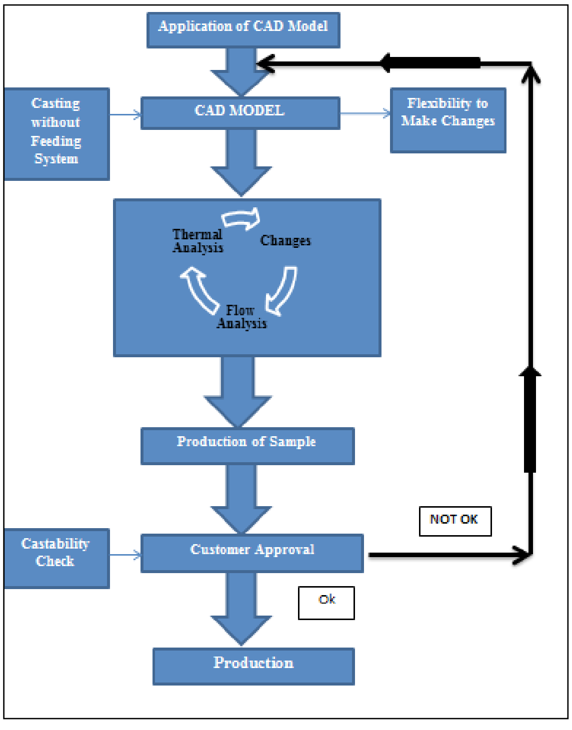

Figure 2.1 Flow pattern of computer simulation

Ravneetkakriaet al [5] He observed that the effects of the selected process parameters on the surface finish and the subsequent optimal settings of the parameters were accomplished using Taguchi's method orthogonal arrays; experiments were conducted as per experimental plans given in this array. The results indicate that the selected parameters significantly affect the surface finish of LM-6 Aluminum alloys castings. The confirmatory experiments have also been carried out to verify the optimal settings of the parameters. V. V. Mane et al [6] he focused on finding process-related causes for individual defects, and optimizing the parameter values to reduce the defects. This is not sufficient for completely eliminating the defects, since parameters related to part, tooling and methods design also affect casting quality, and these are not considered in conventional defect analysis approaches.

3. FE ANALYSIS USING PROCAST

Figure 3.1 shows a flowchart, in which 3D CAD and simulation tools are utilized to improve the system design of the casting. The castings geometries presented here were meshed with MeshCAST, which requires the Generation of a surface mesh before meshing the enclosed region with tetrahedral elements.

Figure 3.1 indicates the path of FE analysis using ProCAST.

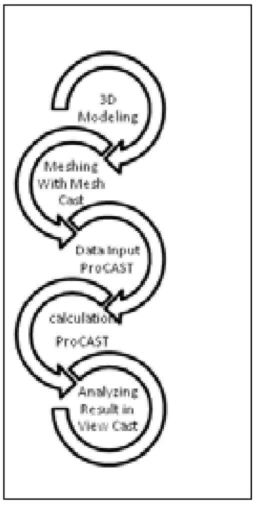

Figure 3.1Steps needed to make a simulation

STEP 1. 3D CAD Modeling:

The modeling has been performed on the Solid works 2009 version and then after the analysis works has been performed on the ANSYS 12.0 version as shown in figure 3.2 and figure 3.3.

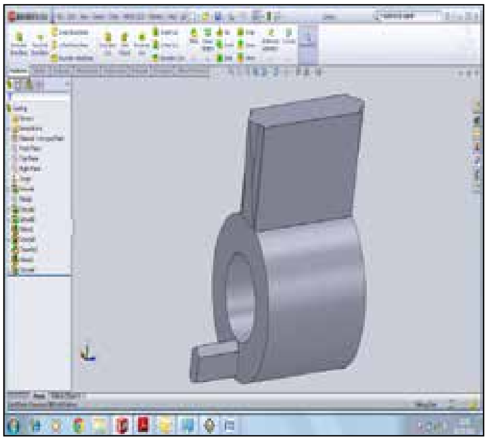

Figure 3.2 Model of Shell Core Drum

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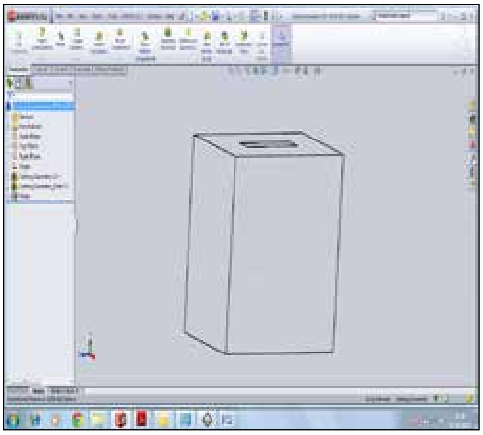

Figure 3.3 Die & Casting

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STEP 2.Meshing with MeshCAST:

The work steps which you follow when using MeshCAST depend upon the following: the nature of your project, the intended use of the meshes generated by MeshCAST and the type and quality of CAD model you use as the initial input as shown in figure 3.4.

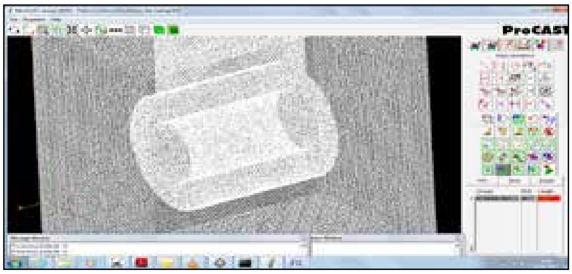

Figure 3.4 Meshing in MeshCAST

- **Import meshing file in PRE CAST:**

After meshing in MeshCAST we import the file in Pre CAST as shown in figure 3.5

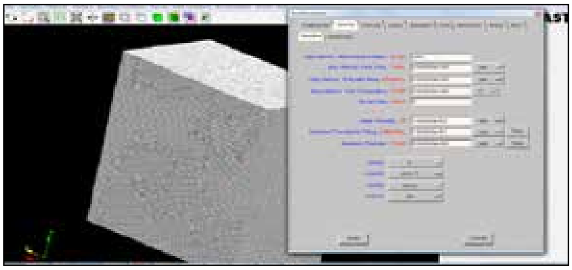

Figure 3.5 Import Meshing File in PRE-CAST

- **Apply Aluminium Casting Initial temperature:**

After applying initial condition for mould we apply initial condition for casting as shown in figure 3.6

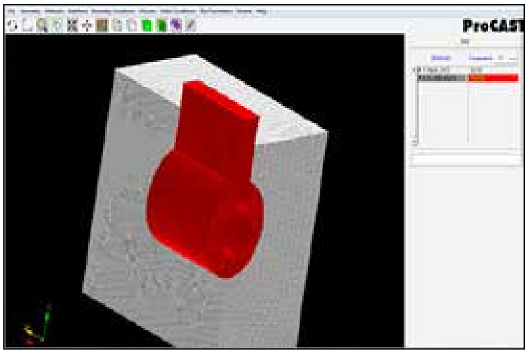

Figure 3.6 Initial Temperature

STEP 3. Data Input to ProCAST

Define Run Parameter for Aluminium Die Casting Simulation. At finally we define the run parameters for die casting as shown in figure 3.7

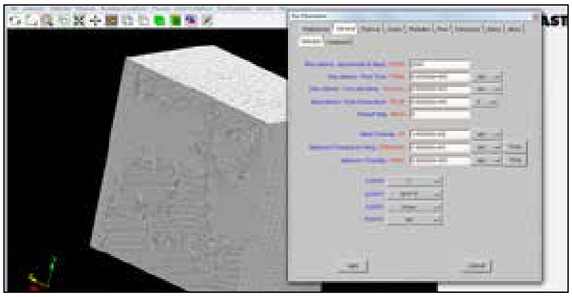

Figure 3.7 Apply Solver Parameters

STEP 4. Calculation:

Initial When Fluid is poured in Mould

Figure 3.8 shows the condition of mould when initial pouring of molten metal

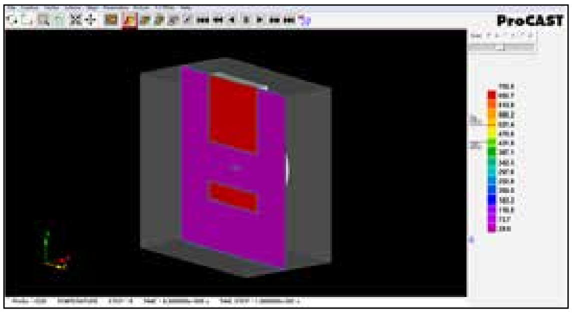

Figure 3.8 Molten state of pouring metal

STEP 5. Analyzing Result:

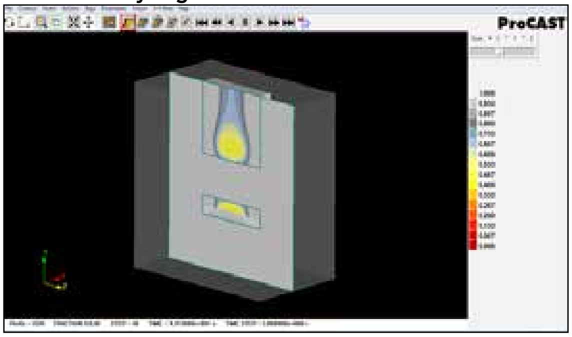

Figure 3.9 Fraction solid Contour

Figure 3.9 shows this solidification Time Contour diagram the highest temperature at a yellow shade. So at that region the maximum chances of occurring porosity because of the upper side of die molten metal are starts to solidify. So the hot gases do not pass through the upper region of the die.

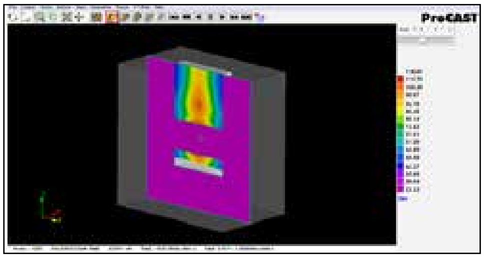

Figure 3.10 Solidification Time Contour

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Figure 3.10 indicates the temperature distribution over entire part. Maximum temperature at the centre of the part so that the maximum chances of porosity occurs at that region. And figure 3.11 shows the perfect location of porosity.

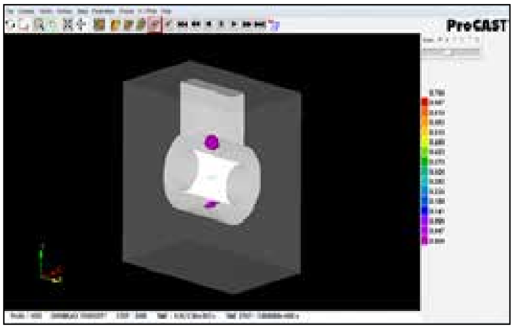

Figure 3.11 Shrinkage Porosity

4. EXPERIMENTAL INVESTIGATE:
Tool Maker Microscope is used to measure the location and size of porosity. As shown in figure 4.1

Figure 4.1 Tool Maker Microscope

Steps:
- Put the work piece on the table of microscope.
- set the lens of microscope at starting of defect.
- start the light and rotate the table as per the defect geometry.
- rotate the screw of table as per defect.
- Get the result.

Tool Maker Microscope automatically generates the graph of defect as well as the perfect location of defect with respect to X-Y-Z axis.

5. COMPARISON OF EXPERIMENTAL RESULT AND PROCAST RESULT:

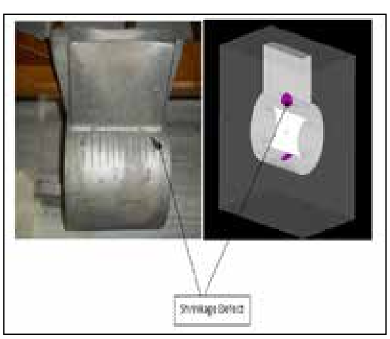

Figure 5.1 Comparisons between ProCAST and Actual Model

Figure 5.1 shows that the location and size of shrinkage porosity is nearer to similar in Experiment and ProCast. By Measuring Porosity Location and size in Microscope we get the nearer result as in ProCAST Experimental results are taken by using Tool Maker Microscope we get the % of porosity is 12.30% and in FE Analysis by using ProCAST we get the % of Porosity is 13.86% as shown in table 5.1

Table no. 5.1
Comparison of Experimental result and ProCAST result

Parameter	Experimental Result	ProCAST Result	Percentage variation
Porosity %	12.30%	13.86%	0.126%

6. ANALYTICAL INVESTIGATION:
The Taguchi method is a commonly adopted approach for optimizing design parameters. The method was originally proposed as a means of improving the quality of products through the application of statistical and engineering concepts. The Taguchi method involves laying out the experimental conditions using specially constructed tables known as "orthogonal arrays". Adopting the Taguchi approach, the number of analytical explorations required to develop a robust design is significantly reduced, with the result that both the overall testing time and the experimental costs are minimized.

Factors: Here in my experiment factors are Runner Height, Runner Width and Riser Height were three factors.

Level: 3
Factors with Level Value: Factors with level values are as given under table 6.1

Table 6.1
Levels of parameters

Factors	Level 1	Level 2	Level 3
Riser Height	70	75	80
Runner Height	111	113	115
Runner Width	43	45	71

By adopting Taguchi method we get the 9 set of parameter as shown in table 6.2

Table 6.2
Different sets of parameters

Modification	Riser Height (mm)	Runner Height (mm)	Runner Width (mm)	% of Porosity
1	70	111	43	11.2
2	70	113	45	12.3
3	70	115	47	13.2
4	75	111	45	10.4
5	75	113	47	8.1
6	75	115	43	12.4
7	80	111	47	9.8
8	80	113	43	12.14
9	80	115	45	12.74

7. RESULT AND DISCUSSION:
After performing analysis of different model of drum with various parameters such as web riser height, runner height and runner width, the % of porosity is measured by ProCAST software as described in earlier chapter. This chapter describes results obtained by analysis and TAGUCHI METHOD.

Minitab offers four types of designed experiments: factorial, response surface, mixture, and Taguchi (robust). The step follow in Minitab to create, analyze, and graph an experi-

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mental design are similar for all design types. After conducting the analysis and entering the results, Minitab provides several analytical and graphing tools to help understand the results.

Taguchi designs experiments using especially constructed tables known as "orthogonal arrays" (OA). The use of these tables makes the design of experiments very easy and consistent. First Minitab version 16 was used for the analysis of result obtained by Finite element analysis. The S/N ratio for % of Porosity smaller-is-better characteristic, which can be calculated as logarithmic transformation of the loss function as shown below. Figure 7.1 shows the table of MINITAB16 worksheet.

Smaller is the better characteristic:

n = -10 Log10 [mean of sum of squares of measured data]

Worksheet 1 ***

↓	C1	C2	C3	C4	C5	C6	C7	C8	C9	C10
	Riser Height	Runner Height	Runner Width	Porosity %	SNRA1	MEAN1	PSNRA1	PMEAN1	PSTDE1	PLSTD1
1	70	111	43	11.20	-20.9844	11.20	-18.6036	8.40444		
2	70	113	45	12.30	-21.7981	12.30				
3	70	115	47	13.20	-22.4115	13.20				
4	75	111	45	10.40	-20.3407	10.40				
5	75	113	47	8.10	-18.1697	8.10				
6	75	115	43	12.40	-21.8684	12.40				
7	80	111	47	9.80	-19.8245	9.80				
8	80	113	43	12.14	-21.6844	12.14				
9	80	115	45	12.74	-22.1034	12.74				

Figure 7.1 Experiment result in Minitab

Main effect plot of means of different parameters are shown in figure 7.2 and response table for means of % of porosity is shown in table 7.2.

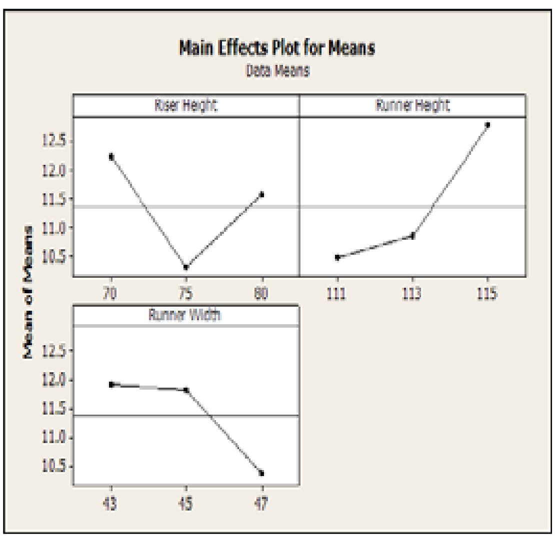

Figure 7.2 Main Effects Plot for Means of % of Porosity

Table 7.1 Response table for Means of % of Porosity

Level	Riser Height	Runner Height	Runner Width
1	12.23	10.47	11.91
2	10.30	10.85	11.81
3	11.56	12.78	10.37
Delta	1.93	2.31	1.55
Rank	2	1	3

From the values of Delta of riser height, runner height and runner width we can conclude that the runner height is most affected parameter as compare to riser height and runner width.

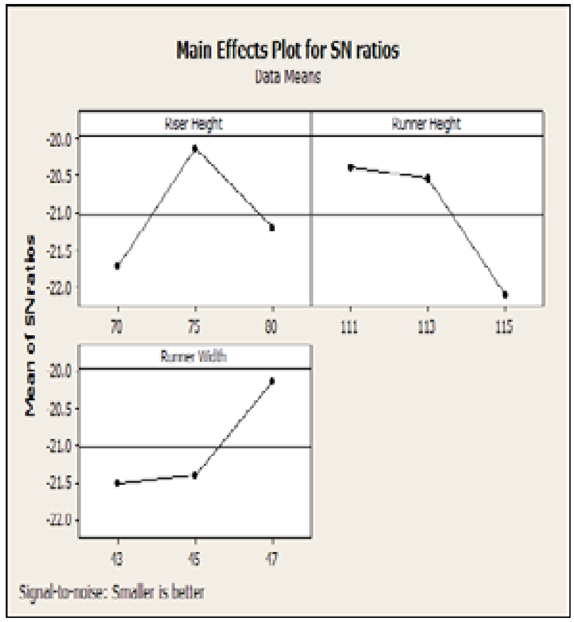

Figure 7.3 Main Effects Plot for S/N ratios of % of Porosity

Table 7.2
Response table for S/N ration of % of Porosity

Level	Riser Height	Runner Height	Runner Width
1	-21.73	-20.38	-21.51
2	-20.13	-20.55	-21.41
3	-21.20	-22.13	-20.14
Delta	1.61	1.74	1.38
Rank	2	1	3

From the above graph we can conclude that the runner height is most affected parameter as compare to riser height and runner width. The Delta Difference is higher compare to other parameter as shown in figure 7.5

The Optimum parameter for minimum porosity is riser height, runner height and runner width is 75 mm, 111 mm, 47 mm respectively as shown in figure 7.3

Table 7.3
Optimum set of Parameter for % of Porosity

Sr. No	Riser Height (mm)	Runner Height (mm)	Runner Width (mm)	S/N ratio	Mean Value
1	75	111	47	18.6036	8.40444

8. CONCLUSION

The Taguchi's approach has been carried out for optimizing the parameters of shell core drum. Three input parameters have been optimized using SNR. The smaller-the-better quality characteristic has been used for minimizing the porosity of the drum. An L_9 orthogonal array with three parameters and three levels has been used for predict set of parameter which gives value of predicated porosity. 9 numbers of experiments were done for those sets of parameters. Experimental values of performance were put in the Minitab software16 and software predicated porosity is 8.4044 % for set of runner height 111 mm, riser height 75 mm and runner width 47 mm. This suggested set of parameter which gives optimum performance of porosity. Validation experiment was done for that set of parameter and compared with predicated value. This experimental value of % of porosity is very closer to the predicated values.

- Result obtained from validation experiments using optimum parameter combination gives excellent agreement

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with predicated results.

- The performance of the optimized model is better than the original model and also prove that taguchi parameter design concept is more powerful and efficient tool for minimize the porosity.
- The FEA based taguchi methods have effectively decrease the time and efforts required for evaluating the design variables.

- **9. ACKNOWLEDGMENT**

Shell core Drum is the product of Mehtex Engineering Pvt. Ltd. (Naroda GIDC - Ahmedabad). I have been greatly benefited Mr. Deepesh Mehta by his valuable suggestions and ideas. It is with great pleasure that I express my deep sense of gratitude to him for his valuable Guidance and constant encouragement throughout this work.

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